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ELECTRONIC CONVERSION BETWEEN EUROPEAN AND NORTH AMERICAN TELEVISION STANDARDS

IN 1964, when the BBC opened its second television service using 625 lines, there was an immediate need for frequency standards conversion between the new standard and the 405-line standard used for BBC-1. The image-transfer standards conversion systems then in use[1] were designed for occasional programmes of topical interest and reliability and operating costs were of secondary importance. These converters also degraded picture quality to an extent which, whilst not objectionable for topical programmes of foreign origin, could not be tolerated for normal evening entertainment programmes.

These considerations prompted the Engineering Division of the BBC to devise standards converters which were cheaper to operate and provided a picture quality near to that of unconverted sources.

These 'line-store' converters[2] did not use cathode-ray or camera tubes, but relied upon electronic circuitry for the operations of storing and modifying the video signals. These were the first fully electronic converters to be used anywhere in the world.

When faced with the problem of converting colour television signals originating on one side of the Atlantic into a waveform conforming to the standards in use on the other side of the Atlantic, it was not surprising that the possibility of all electronic standards conversion for this more difficult problem was seriously considered.

After many theoretical and experimental studies two alternative approaches to the problem of electronic conversion between the European and North American television standards were devised. One approach, whilst much simpler than the other, would result in a converter having certain fundamental limitations,[3] the other approach would result in a more complex converter having none of these limitations.[4]

Because of the need to provide a converter which would transfer colour pictures from one standard to the other at the earliest possible moment, and also because of the formidable technical problems involved in the more complex proposal, it was decided that both approaches should be developed. The simple approach would provide an interim operational converter and at the same time yield valuable experience which would assist in the design of the more complicated, longer-term solution. A converter using the simple approach and capable of converting 525-line 60 field/s NTSC colour signals to 625-line 50 field/s PAL colour signals was demonstrated for the first time in August 1967. This converter has been in regular operational use since that time and has been used in conjunction with live programmes carried by satellite and tape-recorded programmes. A more complex converter will be in operational service during 1968.

In this article some of the important technical problems encountered in a standards converter designed to operate between two colour systems having different field frequencies are considered, and the solutions adopted in the two alternative designs described.

TECHNICAL PROBLEMS OF TRANSATLANTIC COLOUR CONVERSION

The standards used for colour transmissions in Europe and America differ in three ways: the number of lines per field is different, the number of fields per second is different and the coding used for the chrominance signals is also different.

The problem of converting from one colour coding system to another exists not only in transatlantic programme exchanges, but also within Europe where

General view of the electronic field store standards converter.

Eurovision exchanges take place between countries using SECAM and those using PAL. Normally, the change of colour coding system is effected by decoding the incoming chrominance signals after separating the luminance signal and then recoding the colour signals using a new subcarrier. This technique, known as transcoding, is also applicable in the case of standards conversion. The decoding operation[5] can take place at any suitable point within the standards converter, and recoding of the new colour standard is most appropriately carried out at the end of the conversion operation.

The novel problem involved in transatlantic conversion is the change of field frequency by electronic methods. When converting an American television signal to a European signal each field period must be increased in duration from $16\frac{2}{3}$ms to 20ms and the number of fields per second must be reduced from 60 to 50. These two processes are reciprocal in the sense that the increase in field duration is such that the gap left by the omitted field is exactly filled by the extension of the remaining fields. It may also be said that the increase in the number of scanning lines per field is also complementary to the extension in field duration since the extra fifty scanning lines per field will account for the additional $3\frac{1}{3}$ms. When converting in the opposite direction, from Europe to America, the reverse processes must take place.

In order to omit one whole field in every six incoming fields, a delay of one field period must be provided, and for this reason the new converters are called 'field-store' converters. Delay is also necessary in order to increase the number of lines per field, since each new line must, in effect, repeat information carried by earlier incoming lines. The basic principle of omitting or duplicating lines or fields by means of a delay is illustrated in Fig. 1, which shows a delay which may be thought of as equal in duration to one line or one field. The time periods shown above the delay correspond to the same unit, i.e. one line or one field and indicate a continuous flow with respect to time. The periods are numbered 1 to 5 and at the bottom of the diagram the columns of numbers indicate the sequences which will emerge from the two terminals 'a' and 'b'. From terminal 'a' the incoming periods will appear at the time they enter the delay, whilst they will appear at 'b' as they leave the delay.

By switching between terminals 'a' and 'b', any one period can be omitted or repeated according to the direction in which the switch is moved.

If connection is first made to terminals 'a' and 'b', any one period can be omitted or repeated according to the direction in which the switch is moved. If connection is first made to terminal 'b' and after the emergence of period 2 from the delay the switch is connected to terminal 'a', then the sequence —, 1, 2, 4, 5 will emerge from the output terminal of the switch. Period 3 has thus been omitted. Conversely, if the switch is first connected to terminal 'a' and after

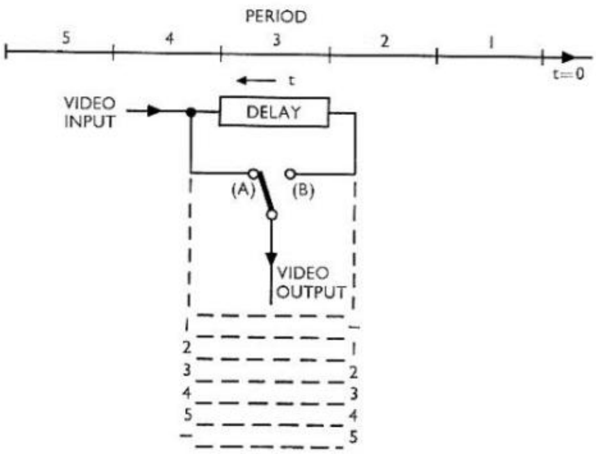

Fig. 1. Omission or duplication of lines or field by means of a switched delay.

the emergence of period 3 is changed to terminal 'b', then the sequence 1, 2, 3, 3, 4, 5 will emerge; in other words, period 3 has been repeated. If it is desired to omit or repeat one line then the delay will have a duration equal to a line period whilst if a field is to be omitted or repeated, the delay must equal one field period.

During the development of the converters for exchanging programmes between BBC-1 and BBC-2, it was realized that the omission or duplication of lines resulted in an unacceptable distortion of the picture. In order to alleviate this effect the technique of 'interpolation' was devised. Experience has shown that interpolation is not only necessary when changing the number of lines in a field,[2] but is also necessary when the number of fields per second is altered.[3]

Fig. 2 shows the effect. The vertical axis represents time and the solid horizontal lines represent the epochs of incoming lines or fields. Similarly the dotted horizontal lines represent the epochs of outgoing lines or fields. Considering first the effect of a change in the number of lines, the diagonal solid line represents a piece of picture detail such as a sloping edge and this is represented by the incoming line samples as discrete picture points, one on each incoming line. If each outgoing line receives its video signal from the nearest preceding input line, the sloping edge will not appear as a straight line in the converted picture but will be serrated, the discontinuities resulting from the omission of one line in every five.

In the case of the omission of one field in every five, the same diagram, Fig. 2, will suffice but the sloping line as describing the position of an object that is moving steadily from the left of the screen to the right must be considered. The solid horizontal lines now represent incoming field periods and the straight diagonal line indicates that the object is moving with uniform velocity. If the video signal on the appropriate incoming field periods, solid horizontal lines, is transferred without modification to the next outgoing field period, dotted horizontal lines, the object will no longer appear to be moving with constant velocity, but will move in a series of jerks as represented by the zig-zag diagonal line.

The use of the same diagram to illustrate the distortions resulting from the omission or duplication of both lines and fields stresses the similarity between the two phenomena. The cure is, not surprisingly, also similar for both distortions. Video signals from consecutive lines, or consecutive fields, must be blended together in suitable proportions to form new video signals which, when fitted into the new lines or

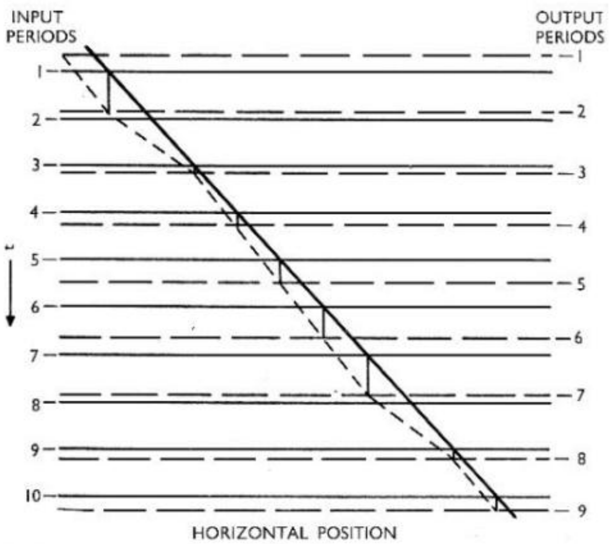

Fig. 2. Illustration of the need for interpolation when lines or fields are omitted.

fields, give more correct representations of the original picture than the unmodified video signal. These processes are referred to as 'line-interpolation' and 'movement-interpolation'.

Once again, some means of delaying video signals by periods of one or more lines and one or more fields is necessary to the interpolation processes, since video signals from earlier lines or fields must be delayed so that they are available simultaneously with later lines or fields.

Changing the number of lines per field and the number of fields per second requires delays equal in duration to line periods and field periods. It can also be seen that interpolation is necessary as a result of these actions, and that interpolation also requires delays equal to line and field periods. The provision of suitable wide-bandwidth delays is one of the major hurdles to be overcome in the design of satisfactory electronic converters for transatlantic programme exchanges.

The most advantageous medium at present available for delays ranging in length up to 20ms is fused quartz. Ultrasonic waves propagate through the quartz with a velocity of about 4mm per microsecond which is about 10^5 times slower than the velocity of electromagnetic waves in conductors. Thus a relatively long delay can be achieved in a physically small unit and bandwidths of several MHz can be obtained without undue difficulty. The television signal is caused to modulate a carrier wave with a frequency between 20 and 40MHz and the modulated carrier is applied to a piezoelectric transducer which is bonded to one facet of a polygonal block of quartz. This transducer generates a narrow beam of ultrasonic vibrations which is reflected several times by other facets of the polygon before impinging upon a second piezoelectric transducer which reconverts the acoustic wave into an electrical signal. A delayed version of the original video signal is then obtained by demodulation.

Both converter designs developed by the BBC use quartz delays as the requirements of television signals demand an exacting specification which can only be met by quartz delays. Other advantages are that these devices offer stability and reliability without maintenance, while a single unit is capable of delaying a television signal for $3\frac{1}{3}$ms without significant impairment.

THE SIMPLER FIELD-STORE CONVERTER

This converter used the simplest possible configuration of quartz delay lines that will permit usable 50 fields per second signal to be obtained from a source of 60 fields per second. In principle only four delays each of $3\frac{1}{3}$ms are required. A simplified block diagram of this converter, Fig. 3(A) and a representation of the relationship between input and output field scanning is shown in Fig. 3(B).

The incoming 525/60 video signal is applied to the four delays which are connected in series. A five-way single-pole switch enables any of the five connections to delays to be selected. At the start of input field 1, the switch is in position (A) and the phasing of the input and output fields, arranged by the sync converter, is such that output field 1 has already been under way for about $1\frac{2}{3}$ms. Thus, on the output picture, the top of input field 1 will appear a short distance below the top of the screen. No change of delay is made during the active field period and this input field will continue to provide a picture until the output field scan is a short distance above the bottom of the screen.

At the end of the first output field the switch contact is moved to position (B) causing the next input field to be delayed by $3\frac{1}{3}$ms. Thus corresponding points on input fields 1 and 2 will now be separated in time by 20ms and the second field will occupy the same position on the output picture as field No. 1. By continuing to increase the delay by $3\frac{1}{3}$ms at the end of the second, third and fourth output fields, the first five input fields will be properly positioned on the first five output fields. At the end of the fifth output field the switch is in position (E) and a delay of $13\frac{1}{3}$ms is in circuit; if the delay were again increased by $3\frac{1}{3}$ the total delay would be $16\frac{2}{3}$ms or one input field period. However, the sixth incoming field must be

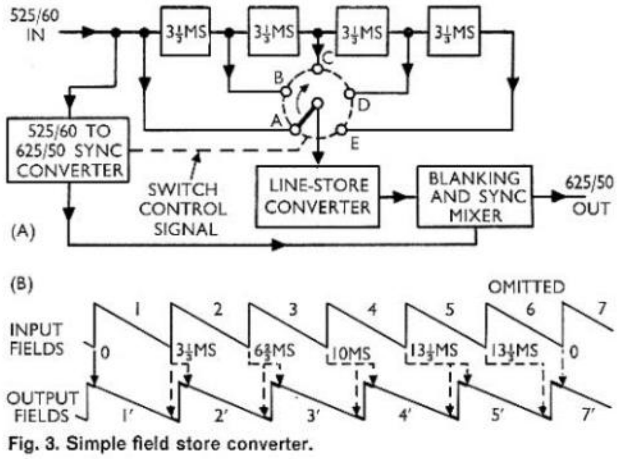

Fig. 3. Simple field store converter.

omitted and if the delay is changed to 0, instead of to $16\frac{2}{3}$ms, this will happen. In other words, the switch is returned to its starting point, position (A), at the end of the fifth output field thus omitting field 6 and beginning the cycle of events all over again.

If the line frequency of the incoming 525/60 video signal were identical to the line frequency of the 625/50 output signal, a coherent picture would be obtained as a result of the above processes. However, the two line frequencies differ slightly and it is necessary to use a line-store converter. Such a converter not only arranges that the video signals are synchronous with the output synchronizing pulses, but also provides the interpolation which is necessary even though the change in line frequency is relatively small.

As the height of the output picture is less than the height of the output raster, the width of the picture must be reduced in proportion to preserve the correct aspect ratio. This is also done by the line-store converter which is designed to read a stored line of video signal in approximately five-sixths of the active line period of the outgoing standard.

In order to convert colour signals, decoding and recoding equipment must be provided. At present line-store converters are not able to deal with composite colour signals and it is therefore convenient to decode at the input to the line-store converter and recode at the output. This means that the line-store converter must be able to convert the luminance signal and two chrominance signals simultaneously and in effect three line-stores must be provided. Since the bandwidths of the two chrominance signals are much less than the bandwidth of the luminance signal, the total capacity required is only about twice that provided by a normal monochrome line-store converter.

It was stated earlier that interpolation is necessary when the field frequency is altered, since moving objects will otherwise appear to judder.

Movement interpolation—as it is called—requires signals from consecutive field periods to be blended together in correct proportions and a delay of one field period is thus essential. It is therefore necessary to add a fifth delay of $3\frac{1}{3}$ms to the four needed for field-frequency conversion, thus making a total delay of one field period from a cascade of five series-connected $3\frac{1}{3}$ms delays. With this arrangement it is possible to form output field 5 from a combination of input fields 5 and 6, Fig. 3(B), and output field 7 from a combination of input fields 6 and 7. The disturbance to rapidly moving objects is thereby reduced to an almost imperceptible level.

The simplicity of this machine results in two disadvantages. Firstly, the picture size is somewhat smaller than normal, and secondly it is necessary to synchronize rigidly the input and output field frequencies. As the American field frequency for colour tansmissions is 59·94Hz whilst that in Europe is 50·00Hz, it is not possible to obtain a completely standard waveform from this simple converter during live international exchanges by satellite. A compromise solution is, however, possible by allowing the normal arithmetic relationship between the output colour subcarrier frequency and the scanning frequencies to lapse. The transmitted signal can then be displayed by receivers but this non-standard signal cannot be satisfactorily recorded by a videotape machine. Thus for some applications it is necessary to use two coders at the output of the converter. One is supplied with a subcarrier that has the correct arithmetic relationship to line frequency and provides a recordable signal. The other is supplied with a subcarrier of the correct absolute frequency and provides a signal suitable for transmission.

An advantage also results from the simplicity of this converter in that it is possible to design a single machine which can operate in two modes: firstly, as a converter providing a 625/50 output from a 525/60 input and, secondly, as a converter working in the opposite direction.

A COMPLEX FIELD-STORE CONVERTER

The more complex converter overcomes the two limitations of the simpler converter, but due to the increased complexity there is no possibility of making a bidirectional machine of this form.

A similar array of $3\frac{1}{3}$ms delays and a multiway switch are used to convert the field frequency but, in order to expand the picture height, an extra cascade of delays is necessary. This second cascade must provide fifty changes of delay per field in order to interleave the additional fifty lines and its total capacity must be $3\frac{1}{3}$ms. Because one-fiftieth of $3\frac{1}{3}$ms is only slightly longer than the duration of one line period, this cascade of delays can be used both to expand the field duration by the correct amount and to add in the exact number of additional lines. The precise delay change that must be made each time a line is added is $66\frac{2}{3}$ and this period is referred to as a 'T' unit.

It would be possible to use fifty delay lines each having a delay of '1T' and a fifty-way switch for this purpose, but the complexity and cost of this arrangement would be excessive. An array using a smaller number of units whose delay times form a binary series is therefore used and Fig. 4 shows the general arrangement. This form of cascade is able to add additional lines since each of the delays has a separate 'bypass' route; signals can be directed via the delay or through the bypass route by the switches which interconnect the delays. These switches can interconnect in either of the two ways shown below the block diagram of the delay cascade; the two input and two output terminals of each switch can be 'cross-connected' as on the left, or 'parallel-connected' as on the right.

The process of adding an extra line can be explained as follows: Assume that initially the extreme left-hand switch is 'parallel-connected' and the second from the left switch is 'cross-connected'.

If two video signals are simultaneously applied to

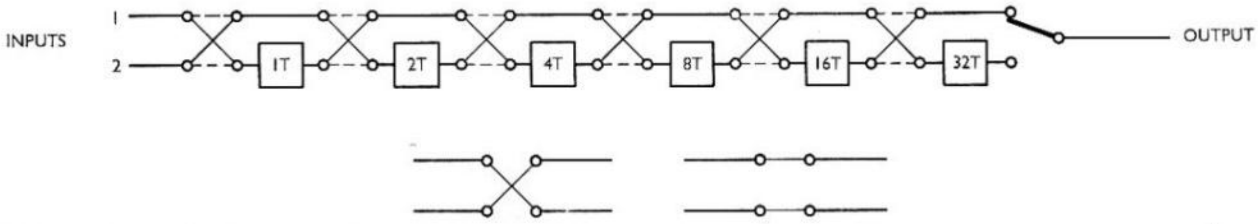

Fig. 4. Binary delay cascade and switches.

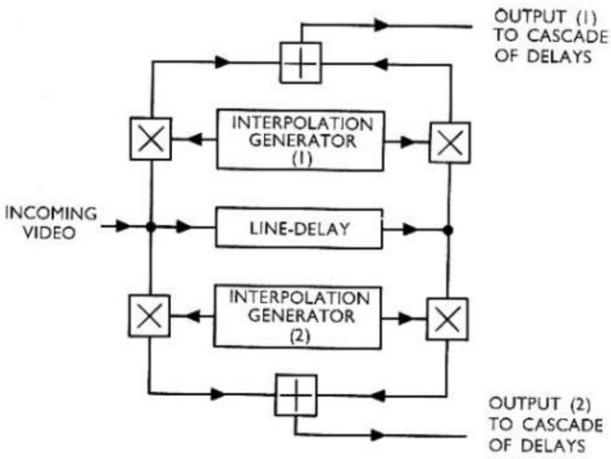

Fig. 5. Line delay interpolater (FSSC).

the two input terminals '1' and '2', then the video signal applied to input '1' will be directed into the delay marked '2T' and the signal at terminal 2 will enter the delay marked '1T'. If at the end of one line period the second switch from the left is changed to 'parallel connection' the line of video signal from terminal 2, which has traversed the '1T' delay, will now follow the line of video signal from terminal 1 into the '2T' delay. Thus, two lines of video signal, which entered terminals 1 and 2 simultaneously, will enter the 2T delay consecutively. Thus the additional 50 lines required by the output signal can be produced simultaneously with other lines in an interpolator and the additional lines can be fitted into the main video signal as it passes through the binary delay cascade.

A form of interpolator that is able to provide two lines of video simultaneously is shown in Fig. 5. The incoming video signal is passed through a one-line period delay and video signals from two consecutive lines are available at its terminals. When one of the extra fifty lines for each output field is needed, two differently weighted additions of the two consecutive lines of video are required and thus two sets of multipliers and two adders must be provided. The two outputs supply terminals '1' and '2' of the binary delay cascade with two different lines of video signal simultaneously.

Although, for simplicity, Fig. 5 shows a line delay as the means of obtaining simultaneous video signals from the input, in practice it is preferable to use a field delay for the purpose. This allows the most appropriate pair of lines from a whole picture to be combined to form each output line and thus provides better interpolation. The field delay can also be used to provide movement interpolation of the form discussed earlier.

A somewhat simplified block diagram of the advanced form of field-store converter is shown in Fig. 6. In the centre of the diagram is the switched array of $3\frac{1}{3}$ms delays which is similar to that used in the simple converter, although an extra $3\frac{1}{3}$ms delay is added, the purpose of which will be explained later. As before, the function of this array is to increase the spacing of incoming fields by $3\frac{1}{3}$ms and to omit input fields when required.

Above the array of switched delays is the binary delay cascade which adds in the fifty extra lines per field that are provided by the interpolator in the top left-hand corner. The binary delay cascade and the switched array of delays can be regarded as fine and coarse delay adjusters. The binary cascade increases its delay in steps of '1T' unit at a time, fifty times per input field period, thus accumulating a total delay of $3\frac{1}{3}$ms by the end of each incoming field period. The switched array increases its delay in steps of $3\frac{1}{3}$ at the end of each field period and this allows the binary

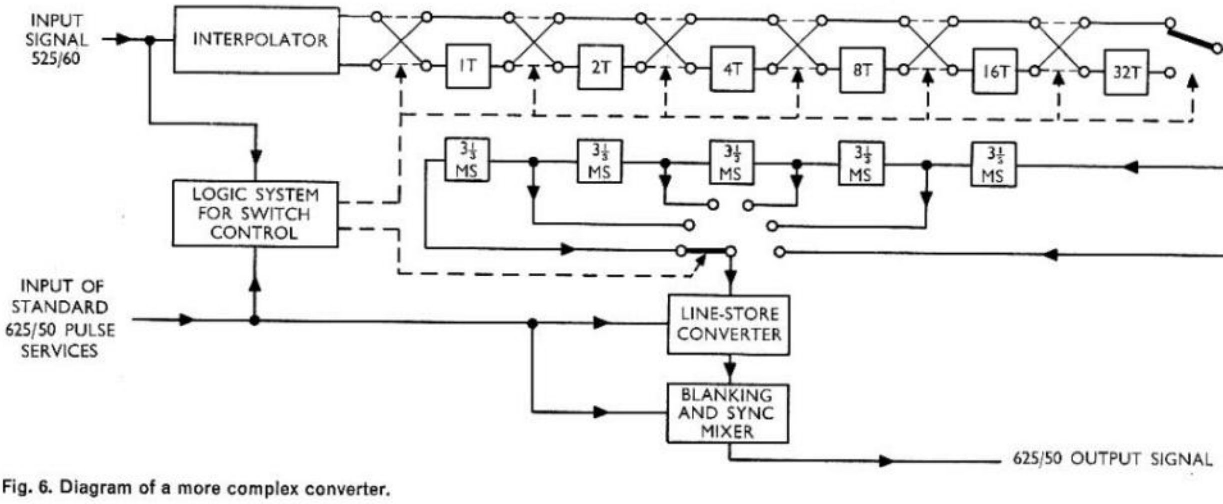

Fig. 6. Diagram of a more complex converter.

cascade to return to zero ready for the start of the next field period.

If the line duration of the incoming 525-line signal were identical to that of the outgoing 625-line signal, then the output signal from the switched array of delays would, when displayed, form a normal full-size picture. However, the input line period is nominally 63·5 whilst that of the output is 64. Thus, the input line periods and output line periods become progressively displaced at a rate of 0·5 per line period. Fifty times each field, when the delay of the binary cascade is increased by one 'T' unit, the input and output line periods will be brought back into step as '1T' unit exceeds an output line period by the required amount. Compensation for this progressive displacement and correction of the phase relationship between input and output line periods require a variable delay of a few microseconds, and this is provided by the line-store converter.

So far the operation of the advanced form of field-store converter has been described in terms of a precise 6 to 5 relationship between input and output field frequencies, but, as mentioned earlier, one of the objectives of the more complex design is to provide a converter which will operate satisfactorily as long as the input and output field frequencies are within their specified tolerances. Therefore it is necessary to allow for the reduced field frequency of 59·94Hz used for colour transmissions on the 525-line system, as well as the nominal monochrome field frequency of 60·00Hz.

The consequences, for the conversion process, of the reduction of input field frequency by 1 part in 1000 can be crystallized thus:

(1) Input field periods will be 16·7 longer. Therefore, after extension by $3\frac{1}{3}$ms, output fields will also be 16·7 too long.

(2) Once in every 1000 input fields, six output fields must be taken from a group of seven consecutive input fields instead of five from six.

The greater length of the resulting field period can be contracted by the line-store converter whose capacity greatly exceeds the few microseconds required to compensate for the differing line periods of the input and output field periods. The occasional need to continue the cycle of the switched array of $3\frac{1}{3}$ms delays for six output fields instead of seven can be satisfied by one additional $3\frac{1}{3}$ms delay, thus accounting for the total of 5 shown in Fig. 6.

The advanced converter is designed to operate from input and output signals which are completely independent, the only stipulation being that the field frequencies are within the specified tolerances. The capacity provided in the fixed delays and in the line-store converter is sufficient to permit this, but the derivation of the required switch connections for the fixed delays by examination of the input and output synchronizing signals requires control logic of considerable complexity.

In this field-store converter it is advantageous to use a special form of colour coding and to transcode the incoming NTSC signal to this new form at the input to the converter. The first reason for adopting a special system of colour coding is that the disturbance to the relationship between subcarrier and line frequencies by the addition of fifty extra lines per field precludes the use of a comb filter for separating luminance and chrominance components at the output of the converter. It is therefore desirable to use a subcarrier frequency sufficiently high to allow satisfactory chrominance/luminance separation by means of low-pass and band-pass filters near the converter output. A second reason is that interpolation must be done before the new lines are added and the line-store converter must follow this process; a separate interpolator at the input of the converter is therefore required and this interpolator can operate on the composite colour signal only if the subcarrier frequency is an integral multiple of line frequency. The special colour subcarrier conveys the R–Y and B–Y chrominance signals through the converter delay lines and switches by double-sideband quadrature modulation, the lower sideband of which does not significantly overlap the luminance spectrum. Decoding of the special colour signal takes place before the line-store converter (which must operate upon all three components at baseband) and recoding to 625-line PAL or SECAM is done at the output of the converter.

CONCLUSIONS

The simple converter has already been in operational service for some months and has now been developed as a two-direction converter. Apart from the inherent limitations described the performance of the simple converter is good and currently provides the only means of converting 525/60 NTSC to 625/50 PAL. A 625/50 to 525/60 version of the advanced converter is also contemplated.

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